

The Clinton Iron-Ore Deposits of Stone Valley, Huntingdon County, Pennsylvania.

A DISSERTATION

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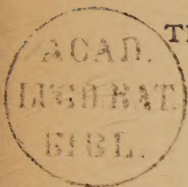
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Huntingdon County, Pa.

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I. DESCRIPTION OF THE CLINTON ORES AND ASSOCIATED ROCKS.

THE Clinton rocks in Stone Valley comprise (1) thick layers of deep-red shale, (2) layers of reddish-gray shale interspersed with beds of sandstone and thin beds of extremely fossiliferous limestone, and (3) yellowish-gray shales alternating with thin layers of olive-colored shales. These layers of shale are all very thin and are at no point massive.¹

A bed of gray-white sandstone varying in thickness from 12 to 30 ft. occurs in the upper portions of the Clinton shales. This is called the ore sandstone, a name given to it by Rogers and adopted also by the Second Pennsylvania Geological Survey. It is the surest guide to the presence of the iron-ore bed, which lies below its lower edges at distances varying from 10 to 20 ft. This ore sandstone, in the valley, lies generally at very low inclinations, but often is locally subjected to considerable changes in dip. At its outcrop this ore sandstone weathers very easily and yields a rather sparse crop of stone, composed of dirty, iron-stained boulders. Upon the roads these boulders are quite well rounded, and bear fragments of crinoid stems and other fossil forms.

The ore sandstone exhibits at many points evidences of former movements in this very great thickness of the shales, and as it is the only stratum in this series competent to transmit and record stresses due to structural movements, its evidence is of considerable importance in determining the occurrence of movements in times past.

¹ L. C. White. The Geology of Huntingdon County, *Second Geological Survey of Pennsylvania, Report of Progress T3*, p. 239 (1885).

1. *Occurrence of the Ore in Brush Ridge.*

A generalized section of the ore-bed and the rocks immediately above and below it in Brush Ridge is practically:

	Feet.
Soil, x feet, usually varies from 5 to 10 ft.	x
Loosely-layered sandstone becoming gray in color,	8 to 20
White sandstone,	3 to 4
Brown sandstone, about	3
"Dirt-vein," from	3 to 4
Brown sandstone, "main roof" of the miners,	3
"Working ground,"	2 to 3
This is taken down in brushing the gangways and hence is called "working ground."	
Ore-bed, averaging 12 in. thick, often as thin as 6 in. and sometimes as thick as 18 in.	
Soft slate, buff in color, of unknown thickness. About 4 ft. of it is taken up in the gangway.	

A section of ore in the first left branch, Hunter Drift, Brush Ridge, is:

	Inches.
Soil,	x
Slate,	6
Lean ore not saved,	4 to 6
Slate,	8
Slate,	2
Ore, generally used when good quality,	2
Yellowish-green slate,	2
Soft, rich iron ore,	12
Soft bottom slate, grayish to yellowish in color,	x

A section of the ore-bed in Benson drift, at the west end of Brush Ridge, is:

	Feet.
Sandstone, brown colored,	12 to 15
Rather hard, yellowish slates,	7 to 9
Soft yellow slate "working ground,"	1.5
Soft, rich ore,	1.0
Bottom slates, yellow and olive-colored, with dirt veins,	3.0

A. *The Ore-Stratum.*—The outcrop at the mill-dam presents the best, and perhaps the only, opportunity of observing the ore-bearing stratum in its original unchanged condition. Here it is a bed of very fossiliferous limestone about 8 or 10 in. thick. The fossils are remains of brachiopods, crinoids, bryozoans, and other organisms. In thin sections the lean ore shows the same organic remains, which will be referred to later. In

color the fossiliferous limestone is a bluish-gray when fresh and unweathered. The weathered edges of the outcropping limestone are dark-brown in color, and small cavities, evidently left by the solution and removal of the fossils, are seen. The weathered portion is of a rather lower specific gravity than the unweathered rock. In the bluish-gray unweathered limestone masses of what is apparently ferrous carbonate can be observed, and a portion of the mass surrounding the supposed siderite is seen to be calcite. This is observed both megascopically and microscopically.

Although the limestone at the mill-dam is one mass of fossil remains, these seem to be confined to bryozoans, brachiopods, crinoids, or smaller forms, and no corals were observed at this point.

Tracing the bed of fossiliferous limestone westward along the ridge, it is found to pass first, at a distance of about half a mile from the mill-dam, into thin, rather lean ore, of little commercial value, and finally into a soft, rich, typical oölitic ore at a distance of about three-fourths of a mile from the mill-dam. The first drifts into the east side of the ridge are at a distance of about half a mile westward from the dam, and from this point to the extreme western end of the ridge (or the Benson drift), waste-heaps from abandoned working-drifts are found every few hundred feet. At most of the drifts the larger portion of the material on the waste-heaps is composed of soft shales, greatly weathered, together with small pieces of soft, rich ore, but at two drifts, viz., the Hufford drift and the Parker, or road drift, about two miles west from the dam, there is a considerable quantity of hard ore lying on the waste-heap. Masses of hard ore are also found in the Bookhammer drift, at present in operation, which produces soft ore as well. This hard ore is similar in appearance to the soft ore, that is, it is oölitic, but is apparently cemented by silica and contains remains of corals not found in the soft ore. These corals are *heliolites* and are of CaCO_3 ; in addition to the limestone corals, which are clearly defined against the hard ore and are not at all replaced by the iron, masses of gray-blue shale appear in the hard ore.

As the ore is followed in its course from the Parker drift westward its color changes from brick-red to a dull black at

the Mule drift. This latter ore is reputed to be the richest ore dug on the ridge. The ore in the Bookhammer and Benson drifts, a short distance westward from the Mule drift, is of the ordinary brick-red color characteristic of the other drifts.

All through the ridge, but more especially towards the western end, the ore-bed is found to be much contorted. The average dip is about 10° to 15° , but rises to as much as 55° in some places, and is often overturned.

Jointing, both primary and secondary, is observed in the ore-bed. These joints are always found full of water when first opened. Vugs filled with clay are also found near the joints. Below the ore-bed lies a dark olive-colored shale. Apparently the slope of the ridge over the ore-bed has considerable influence on the richness or leanness of the ore. Over the Mule drift the surface-slope is quite gradual, being about 5° . The miners report that, as a rule, soft ore occurs under the ravines and hard ore under the rolls. They also affirm that if, in drifting across the measures to reach the ore-bed, shale or slate is met with before reaching the ore sandstone, the ore sandstone is hard, unbroken, and unweathered, and the ore below the sandstone is also hard. Where the ore sandstone lies under soil only and is broken, the ore below is soft and rich. The ore is hard and lean under the minor rolls on the slope of the ridge and soft under the ravines. The hard ore occurs as points or triangular-shaped bodies with their pointed ends pointing up the slope of the ridge.

Ground-water is found in the slates and shales under the hard ore, while it occurs in the shales and slates over the soft ore in the same bed. This change occurs within very short distances.

The ore sandstone seems to retain and carry the water and, apparently, has an intimate relation with the richness of the ore. There is considerable ground-water in all the mines, and most of the abandoned drifts, where good, soft ore was found and worked, have issuing from them small streams of water of excellent quality. Aside from the occurrence at the mill-dam no outcrops of either soft or hard ore in place are found on Brush Ridge, though elsewhere in Stone Valley several such exposures of soft ore are found. Occasionally masses of iron pyrites are found in the center of masses of solid, massive

hematite, but the aggregate amount of such finds is not large. In the Bookhammer drift the "working ground" overlying the ore-bed is found to be of fair quality, though hard and unsuited for reduction in a charcoal cold-blast furnace. Old miners report such occurrences common in earlier workings on the ridge.

B. *Topographical Conditions.*—Brush Ridge is a low and rather narrow monoclinal, between 2 and 3 miles long, composed of Clinton strata. At no point throughout its entire length does the ridge rise to any considerable height, being usually at an elevation of from 200 to 500 ft. above the drainage-level of the region. It has undergone considerable erosion and the surface is well-rounded. Numerous ravines cut the north side, which is composed of the outcropping edges of the shales, but the southern slope is quite gradual, varying from 10° to 15° , and is cut by very few ravines and these few are minor ones. No good exposures of the rocks are seen at any point along the southern slope except near the mill-dam at the eastern end of the ridge. The mines are all at or near the western end of the ridge, at which point the soil is brick-red to yellow in color, soft and rather sandy.

At the mill-dam the ore-bed lies nearly horizontal, with a dip to the SW. of not more than 4° , which increases to between 10° and 15° within a quarter of a mile west from the mill-dam. There seems to be a definite relationship between the angle of inclination at which the iron-ore bed lies, the slope of the overlying surface, and the richness of the ore. For example, the ore is lean and contains a large percentage of CaCO_3 at the mill-dam, where it lies nearly horizontal and is covered by heavy dark-gray unweathered shale, which lies at a dip of about 20° . As the ridge road is followed westward from the mill-dam the soil changes in color from dark gray to a buff color and rounded, worm-eaten pieces of ore sandstone appear in it. The ore sandstone is broken, lies near the surface of the ground, and is not covered by shale. Under such conditions the iron-ore bed is generally found soft and rich. Moreover, at all points where the ore-bed outcrops in other portions of Stone Valley between Standing Stone and Tussey mountains, the surface-material over the rich, soft ore-beds always lies at a slope of between 10° and 20° .

Here and there on the southern slope are small minor ravines which carry the drainage in times of storm. Under most of these ravines, as far as the mine-workings have penetrated, there is generally found soft, rich ore. Under the minor rolls lying between these small ravines carrying wet-weather streams, the ore is, as a rule, hard, siliceous, and lean.

The county-road leading from Greenwood Furnace to Huntingdon extends along the foot of the eastern slope of Brush Ridge and defines almost exactly the line denoting the boundary between the soft, rich, fossil ore lying above it and the hard, lean, unaltered ore lying below it. In all the cross-cuts driven to reach the ore-bed in Brush Ridge it has been found that this is prevailing the case.

As the road is followed south from Greenwood Furnace the ridge is seen to decrease in height, and the slope of the eastern side is more gradual and the outlines are more rounded.

2. *Physical Characters of the Clinton Ore in Stone Valley.*

The Clinton iron-ore in Stone Valley is very similar to the typical oölitic Clinton ore found in New York and other States, and often called fossil ore. It can be divided roughly into two varieties, hard ore and soft ore. The former variety is not used here in the manufacture of iron, as, owing to its refractory nature, it is unadapted to smelting in the charcoal cold-blast furnaces in Stone Valley; it is also mined with difficulty, carries considerable silica, and uniformly occurs under the hog-backs, or small local rolls, in the side of Brush Ridge. Many organic remains are found in this ore, such as corals, brachiopods, and crinoid stems. Scales of micaceous hematite also occur in it.

The soft ore is composed of small oörites, can be rather cheaply mined, and is easily reduced in the charcoal-furnace. If unweathered, the ore is hard, calcareous, and lean, and contains many fossil remains; but if soft, few organic remains are discernible in it. Jointing is quite well shown in both the hard and the soft ore.

The ore can be found in all varieties, grading from the gray-blue limestone, containing but a small percentage of iron and composed almost entirely of organic remains (chiefly brachiopod shells) through the hard, lean, and siliceous ore to the soft, rich,

granular ore. The oölitic character is prominent in both the hard and soft ore, but the brachiopod remains, so numerous in the limestone at the outcrop, have nearly all disappeared from the hard ore, and are rarely observed in the specimens of soft ore. At the mill-dam the outcrop of the ore is merely a bluish-gray limestone, made up almost entirely of remains of shells and crinoid stems.

The soft ore when freshly mined is quite soft and is easily dug with the pick, but hardens somewhat when exposed to the air. The hard ore is mined only with difficulty. Both varieties of ore occur in the same bed, and they grade into each other and seem to bear important relations to the topography and drainage of the surface.

A. *Oölitic Structure*.—Like all other occurrences of Clinton iron-ore, that of Stone Valley is oölitic, the grains being about 1 mm. in size, and of various shapes, some being spherical, others oval, and still others having their longitudinal dimension much greater than their cross dimensions. The oölitic structure is plainly visible megascopically in all varieties, both hard and soft, except in the lean ore at the mill-dam. Beyond the mill-dam the fossils disappear almost entirely, and the ore, both in hard and soft varieties, is truly oölitic, though brachiopod remains occur occasionally in the hard ore and rarely in the soft ore.

The ovules, when freshly mined, are brownish-red in color and of earthy appearance, but in the hard variety the oölites on drying harden and become glazed, and have a reddish-brown color, resembling very much in shape and appearance ordinary flax-seed. These oölites have their long dimension approximately horizontal, and cause the ore-masses to cleave easily in that direction.

B. *Concretions*.—The mass of the ore, both hard and soft, is composed of concretions of a diameter of about 1 mm. These concretions are apparently made up of coatings of iron oxide about a center of some hard material, evidently organic in character and sometimes composed of calcite. They are of various shapes, some much greater in length than in width, others oval in form, and still others circular in cross-section. The nucleus is, in some cases, calcareous, bearing coatings of iron oxide on its outer surface, and between the concretions the

cementing material is also calcareous in character and evidently calcite, as the interference-colors with crossed nicols and the cleavage-lines seem to indicate this mineral. Relatively, only a portion of the bed is ore-bearing. Under the microscope, by far the larger portion of the field is occupied by the calcite forming the filling between the concretions, the iron coatings on the concretions being a minor constituent in the field.

Cross-sections of these concretions yield, in thin sections, a remarkably regular structure.

Sections for microscopic examination were cut from specimens of both hard and soft ore, but the former yielded much better results than the latter, as, owing to the nature of the soft ore, it was very difficult to secure thin sections. Although the greater portion of the sections examined came from the hard ore, sections were cut from hand-specimens showing the limestone in all stages of the transition from fossiliferous, lean, gray-blue limestone to the soft, rich ore. In all the rock- and ore-sections examined the concretions were found in varying quantities. They were recognized in the limestone at the outcrop near the mill-dam, in the hard ore, where the coating of iron oxide rendered their outlines conspicuous, and in the soft ore, though here their outlines were, to a certain extent, masked by the soft ore in the grinding.

These concretions are associated with other forms, probably bryozoans, and are undoubtedly organic in character. About 4 g. of the soft ore was treated with dilute hydrochloric acid in a Gooch crucible for one week, and the residue, after being well dried in a dessicator, was mounted in Canada balsam. The resulting material, apparently siliceous, seemed to be mostly amorphous in character, but occasional bodies, possessing the characteristics of concretions, were found after the material was mounted. These concretions gave interference-colors of quartz and an axial cross under the microscope, and were made up of successive coatings of silica, which was stained with iron oxide. It was not possible to use a high power upon the concretions, as, owing to their very delicate structure, they could only be mounted with extreme difficulty and the results yielded thick sections. A very slight contact with the needle-point sufficed to cause the kernel to separate from the outer coatings or caused a separation between the individual coatings. Even

a very little pressure upon the cover-glass resulted in the breaking-up of the concretions. All that were successfully mounted, however, exhibited the concentric structure and the axial cross with crossed nicols. The silica seemed, in every case examined, to be stained with iron. Not more than four successive coatings were recognized in any case, but this does not prove that there were not additional coatings present, as it was only possible to use a low-power objective for the above-given reasons. In nearly every case the concretions were oval in shape, though occasional ones possessing circular cross-sections were observed. The oval shape may have resulted from structural movements incidental to causes of dehydration of these ores. Samples of both hard and soft ore yielded concretions, though they were much more abundant in the siliceous residue resulting from treatment of the former variety with hydrochloric acid than in that from the latter. When the siliceous residue was immersed in turpentine and placed under the microscope, the concretions could be plainly seen with a low power. With every slight movement of the watch-glass the concretions turned over, revealing the fact that they were very thin in respect to their length and width. They appeared nearly as thin, looking at them edgewise and parallel to their long dimension, as they would appear if taken from a microscopic rock-section. These iron-stained siliceous oölites, usually of oval shape, have a very glassy appearance with plane polarized light, but with crossed nicols they show their concentric character. They are a relatively minor constituent, judging from the amount yielded by treating both varieties of the ore with hydrochloric acid.

3. *Chemical Character of the Clinton Ore of Stone Valley.*

The most striking result brought to light by the analysis of the two samples of soft and hard ore, given later, is the very large amount of calcium carbonate contained in the latter as compared with the soft ore. This result is quite in accordance with the conditions at all mines where hard ore was found. Masses of blue-gray limestone and corals were found in all the hard-ore occurrences.

It will be noticed that there is a very great difference in the amount of insoluble siliceous material in the two varieties of

ore, the hard ore having but 3.58 per cent., while the soft ore contains 16.40 per cent. The siliceous concretions contained iron oxide stains even after having been treated with hydrochloric acid for some time. This would seem to indicate that the iron and silica of these concretions were deposited together, as claimed by Professor Smyth,² and that they are so much more numerous in the soft ore than in the hard ore, where the unchanged limestone occurs, indicates that the solutions carrying silica and iron effected the replacement of the limestone of the ore-bed. The gray- and olive-colored bands of varying thickness, scattered through the Clinton shales, which owe their color probably to the presence of ferrous silicates, may have yielded a portion of the iron. The following analyses of ore and limestone are of interest:

*Bulk Sample of Soft Ore Taken from All Operating Mines on
Brush Ridge, Huntingdon County, Pa.*

Specific gravity, 4.424.						Per Cent.
Ferric oxide (Fe_2O_3),	.	.	.	.	.	68.35
Alumina (Al_2O_3),	.	.	.	.	.	5.33
Calcium oxide (CaO),	.	.	.	.	.	0.16
Magnesium oxide (MgO),	.	.	.	.	.	0.04
Manganous oxide (MnO),	.	.	.	.	.	0.31
Potassium oxide (K_2O),	.	.	.	.	.	0.48
Phosphoric acid (P_2O_5),	.	.	.	.	.	0.52
Sulphuric acid (SO_3),	.	.	.	.	.	none
Carbonic acid (CO_2),	.	.	.	.	.	0.16
Water and organic,	.	.	.	.	.	8.15
Insoluble siliceous material,	.	.	.	.	.	16.40
						99.90
Insoluble siliceous material.						
Insoluble silica (SiO_2),	.	.	.	.	.	12.03
Soluble silica (SiO_2),	.	.	.	.	.	3.15
Ferrous oxide (FeO),	.	.	.	.	.	0.16
Alumina (Al_2O_3),	.	.	.	.	.	1.06
						16.40

Hard Ore, Parker Drift, Brush Ridge.

Specific gravity, 3.495.						Per Cent.
Ferric oxide (Fe_2O_3),	.	.	.	.	.	48.06
Ferrous oxide (FeO),	.	.	.	.	.	1.44
Alumina (Al_2O_3),	.	.	.	.	.	4.02
Calcium oxide (CaO),	.	.	.	.	.	22.06

² On the Clinton Iron Ore, *American Journal of Science*, Third Series, vol. xliii., No. 258, pp. 487 to 496 (June, 1892).

	Per Cent.
Magnesium oxide (MgO),	0.56
Manganous oxide (MnO),	0.17
Potassium oxide (K ₂ O),	0.19
Phosphoric acid (P ₂ O ₅),	1.04
Sulphuric acid (SO ₃),	none
Carbonic acid (CO ₂),	18.84
Insoluble siliceous material,	3.58
	99.96
Insoluble siliceous material.	
Silica (SiO ₂),	2.58
Ferrous oxide (FeO),	0.22
Alumina (Al ₂ O ₃),	0.78
	3.58

Fossiliferous Limestone from Mill-Dam, Brush Ridge.

	Specific gravity, 2.696.	Per Cent.
Insoluble siliceous material,		15.88
Calcium oxide (CaO),		41.60
Magnesium oxide (MgO),		0.37
Ferrous oxide (FeO),		2.12
Ferric oxide (Fe ₂ O ₃),		2.35
Alumina (Al ₂ O ₃),		1.62
Phosphoric acid (P ₂ O ₅),		0.17
Carbonic acid (CO ₂),		34.16
Loss on ignition,		1.62
Undetermined,		0.11
		100.00
Insoluble siliceous material.		
Silica (SiO ₂),		12.44
Ferrous oxide (FeO),		0.48
Alumina (Al ₂ O ₃),		2.96
		15.88

4. *Fossils.*

Organic remains are found in varying proportion all through the single bed of ore near Brush Ridge. In the lean calcareous ore at the mill-dam they make up the entire mass of the rock, and brachiopod shells, portions of crinoid stems, and other organic remains are very abundant. As the bed becomes richer in ore, fossils are less abundant, until in the hard and soft varieties of ore, remains of organisms, except the oölites, are exceptional. Occasionally brachiopod shells replaced by hematite, and fossil casts composed of the same material, are found in the soft ore, but these occurrences are relatively rare. In the hard ore, however, organic remains are more numerous,

brachiopod shells and corals occurring in nearly every bed examined.

At one drift, viz., the Parker, or road drift, remains of corals, wholly composed of calcium carbonate, were found. These corals were very well preserved, and it was possible, after cutting sections from them, to determine the species. A few brachiopod remains, poorly preserved, were also found at this point. These corals all occur imbedded in hard ore and lie with their long dimension parallel to the bedding of the ore. Scales of micaceous hematite were also found associated with these coral remains at the Parker drift. Indeed, an examination of nearly every find of hard ore along Brush Ridge yielded coral remains in an excellent state of preservation, but as the quantity of hard ore at the Parker drift was greater than at any other drift, this drift yielded the majority of the specimens of corals.

5. *Key-Rocks for Locating the Iron-Ore.*

A. *The Ore Sandstone.*—The ore sandstone in Brush Ridge is usually very much weathered to brown-gray, considerably worm-eaten masses, which are solid at very few places. At one point, the Evans drift, about midway between the two extreme ends of the ridge, the ore sandstone is, however, found massive and extremely hard. Under this hard stone, however, no workable ore was found.

The ore sandstone varies in thickness from 12 to 30 ft. The distance driven in it, to reach the ore, by the drifts or cross-cuts, is about 80 ft. Toward its upper portion the ore sandstone, when massive, is in beds from 2 to 4 ft. thick, but its lower layers are always soft and iron-stained.

When weathered, the ore sandstone is shown to be traversed by thin iron-stained bands, a fraction of an inch in thickness, and running parallel to the bedding. This feature of the weathering is especially well-marked in the exposures at the Evans drift.

When bleached white by exposure to the sun and weather, the ore sandstone shows fossil casts, shells, and crinoid stems, and presents a porous, spongy appearance. Where the ore sandstone is overlain by shale, in place and unweathered, the

ore below the ore sandstone is hard and lean; on the other hand, when there is no unweathered shale overlying the ore sandstone, and the ore sandstone is broken by vertical jointings (as it is at nearly every place near the western end of the ridge), the ore below is soft and rich.

B. *The Clinton Lower Shales.*—The shale overlying the ore sandstone gradually changes in character beyond the mill-dam. There it is hard, dark-gray in color, and has undergone very little weathering and the soil is of a dirty-gray color. But farther along the ridge the shale is soft, yellow to buff in color, and apparently has been very much weathered, and the soil is buff to brick-red in color. Percolating waters have penetrated to all portions of the mass of shale lying over the ore, and the freshly-mined shale has an unctuous feel when held between the fingers.

Scattered along the county-road are many worked-out drifts with their old waste-heaps. At all these openings the shale presents the porous, worm-eaten appearance indicative of the action of percolating waters. At most of the drifts the ore sandstone is covered only by the soil resulting from the weathering of the overlying shale, and the ore sandstone boulders are at the surface. At one point, the Evans drift, however, the shale was found overlying the ore sandstone to a depth of about 10 ft. The Evans drift was driven in a roll between two minor ravines carrying wet-weather streams. It is situated about midway between the two extreme ends of the ridge, on its eastern slope. The ore sandstone was here found to be unbroken under the roll (though broken ground and ore sandstone boulders appeared about 200 ft. to the west of it) and was extremely hard. So difficult was the work of drilling this rock that the drift was abandoned. Some lean ore was found in the ore sandstone, which was banded parallel to the bedding, but no soft ore was ever found in this drift. The miners report that wherever the shale is found overlying the ore sandstone the ore below the latter is hard, indicating a connection between the weathering of the shale and the richness of the ore.

II. THE ORIGIN OF THE CLINTON IRON-ORES.

1. *Previous Interpretations.*

There is very little literature dealing with the occurrence and mode of origin of the Clinton ores. Several of the State Geological Surveys have noted the presence of Clinton iron-ores in their respective States and have made reference to them in their reports, but, on the whole, very little careful scientific work in regard to the origin of these ores has been performed. However, the question is a very interesting one and has lately engaged the attention of several careful workers. In the following pages a *résumé* of the most important articles is given.

The Clinton iron-ores are clearly bedded deposits, and must, as is commonly accepted, owe their richness of iron-content to four causes: (1), to an original deposition of the iron, at the time the present ore-beds were laid down; (2), to a removal of the soluble constituents of the present ore-bed—probably calcium carbonate—and a resultant relative enrichment of the ore-bed, the iron being left by the solution which carried away the calcium carbonate; (3), to the addition of iron from extraneous sources and an absolute enrichment, or (4), to a combination of two or all of these processes.

The following brief summary of the views held by the quoted authorities, shows that they may be clearly grouped in three categories, viz.: (1) According to Newberry and Chamberlin, the ore-formation is due to original deposition of the iron-content. (2) According to Shaler, Russell (in part), and Foerste, the ore-formation is the result of secondary enrichment. (3) According to Smyth, the iron-content is due to original deposition and a subsequent relative enrichment by the removal of the calcium carbonate.

Prof. H. D. Rogers.³ Clinton ores originated like other sedimentary rocks, their iron-content being derived from the waste of surrounding rocks and laid down at the same time the ore-bearing bed was deposited. There was also an additional deposition of iron from the overlying shales and a relative

³ *Proceedings of the Boston Society of Natural History*, vol. vi., pp. 340, 341 (1858). Iron Ores of the Sargent [Clinton] Series, *Geology of Pennsylvania*, vol. ii., p. 729 (1858).

increase in the iron-content of the bed, due to weathering action.

Prof. N. S. Shaler.⁴ The ores were not included in the present iron-ore beds at the time of their deposition, as conditions varied so much at different points that this would have been impossible. The ore-occurrences are due to replacement of limestone-beds by iron-bearing solutions derived from overlying shales. The iron could not have been deposited as far from shore as the limestones were.

Prof. J. S. Newberry⁵ declared that the Clinton deposits were marine and not marsh deposits. The iron was derived from the drainage of the rocks to the northeast of the Clinton sea, and deposited as are the Swedish-lakes ores, *i. e.*, it is an original deposition. While in transportation the iron was soluble protoxide, but became insoluble by oxidation, and was laid down as limonite, which later became dehydrated. Crinoid fragments served as nuclei for the concretions. The large amount of phosphorus in the ore indicated organic origin.

Prof. T. C. Chamberlin⁶ found no marine fossils in the Wisconsin deposits of Clinton age and accepted Newberry's theory of the origin as similar to that of the "mustard-seed" ore of the Swedish lakes.

He concluded that the oölites arose from successive concretions of iron oxide about quartz-grains as a nuclei.

Prof. I. C. Russell⁷ asserted that the main factor in the formation of Clinton iron-ore beds was the influence of weathering, and thought this was indicated by the appearance and chemical composition of the ores at various horizons. Where unweathered the ore was thicker than where weathered.

Dr. Aug. F. Foerste⁸ brought out the fact that the oölitic grains did not manifest the spherical character of oölites of other geological age, and that they were probably bryozoan fragments. Iron oxide has replaced the bryozoan fragments to

⁴ *Notes on the Investigations of the Kentucky Geological Survey During the Years 1873, 1874, and 1875*, pt. iii., vol. iii., 2d ser., p. 163 (1877).

⁵ *Geological Survey of Ohio, Geology*, vol. iii., pp. 5-7 (1878).

⁶ *Geology of Wisconsin*, 1873-1879, vol. i., p. 179 (1883).

⁷ *Subaërial Decay of Rocks and Origin of the Red Color of Certain Formations*, *Bulletin No. 52, U. S. Geological Survey*, p. 22 (1889).

⁸ *On the Clinton Oölitic Iron Ores*, *American Journal of Science*, Third Series, vol. xli., No. 241, pp. 28 to 29 (January, 1891).

a greater or less degree, as well as the cementing material between the various fragments. He did not think that the oölitic character was due to concretionary segregation of iron oxide, but to the gradual replacement of bryozoan fragments.

Prof. C. H. Smyth, Jr.,⁹ thought that the application of the replacement theory to the Clinton iron-ore was not warranted by the facts in the case. The iron could not have passed through calcareous rocks without being precipitated by them, yet the ore occurred, in some places, overlain by limestones and calcareous shales. He found that the concretions in the lean ore are as ferruginous as those in the rich ore. Accordingly the substitution of the fossil fragments took place previous to their consolidation into a bed by the cementing material. If the ore is a replaced limestone, ferrous carbonate should be found, and yet it has never been discovered. The iron did not come from above, for Clinton ore-beds are often found lying horizontal with no chance for the action of percolating waters. There was an original deposition of ore. No iron has been added to the bed since its deposition; there has simply been a removal of the calcium carbonate and a relative enrichment of the bed in iron. The iron is secondary with respect to the organic fragments, but is primary with respect to the ore-bed. In some localities the weathering-action has been more important than at others. He concluded that the iron oxide and silica had been deposited together from solution in meteoric waters. The iron was retained in such waters by organic matter. There is an intimate connection between silicic acid and organic matter which leads to combinations of silicic acid, iron, and organic acids in soils and a deposition of the iron and silica together. The oölites were not originally calcareous.

2. Genetic Phenomena of Stone Valley Ores.

An examination of the Stone Valley occurrences seems to indicate that the ore-beds must occur under certain topographic conditions in order to insure an iron-content sufficient

⁹ Die Hämatite von Clinton in den östlichen Vereinigten Staaten, *Zeitschrift für praktische Geologie*, vol. ii., pp. 304 to 313 (August, 1894), and On the Clinton Iron Ore, *American Journal of Science*, Third Series, vol. xliii., No. 258, pp. 487 to 496 (June, 1892).



FIG. 1.—HARD ORE. MAGNIFIED ABOUT 40 DIAMETERS.



FIG. 2.—HARD ORE, PARKER DRIFT. IRON CONCRETIONS HAVING AS NUCLEI
BROKEN CRINOID FRAGMENTS. MAGNIFIED ABOUT 40 DIAMETERS.

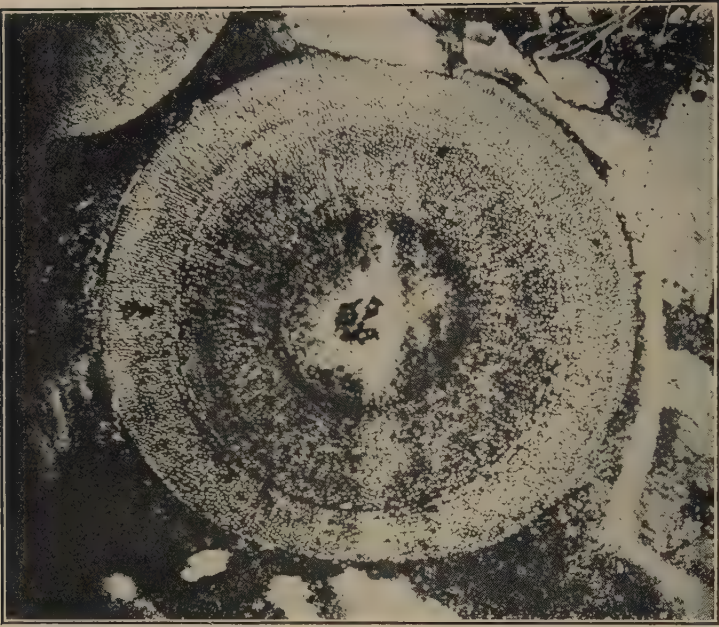


FIG. 3.—HARD ORE. CRINOID PLATES. MATERIAL OF DISK IS CALCITE.
MAGNIFIED ABOUT 40 DIAMETERS.

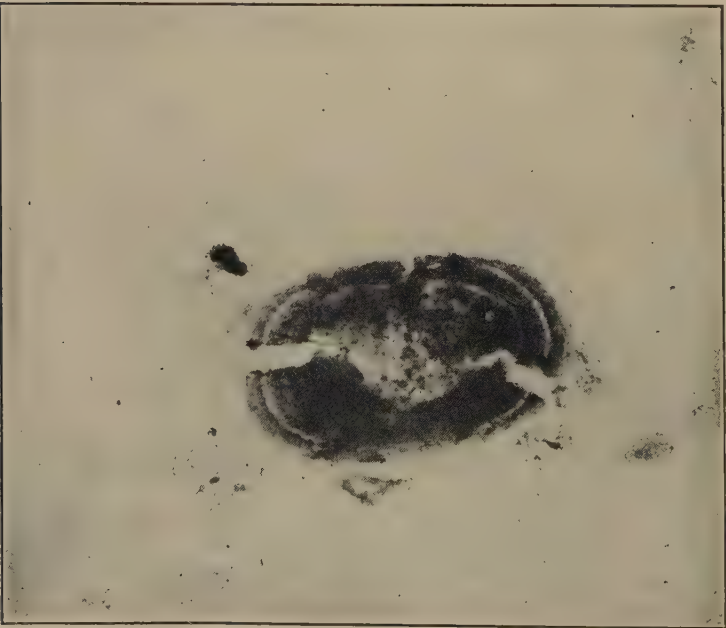


FIG. 4.—SILICEOUS CONCRETIONS. MAGNIFIED 40 DIAMETERS.

to make them of economic importance. Throughout the valley they lie upon the sides of small ridges, the outcrop of the beds usually lying close along the strike of the ridge in conditions favorable to an easy and slow movement of meteoric waters. Moreover, the richer ore-beds generally lie at about the same angle of dip as do the sloping sides of the ridge above them, and a rich bed has usually a dip as great as 10° or 15° or greater.

The second important factor is weathering. At all the occurrences the action of the atmospheric and meteoric waters is noticeable. Where the topographic requisites are fulfilled weathering results, and the appearance of the buff- and red-colored clays resulting from the weathering of the shales indicates to the prospector the likelihood of soft ores below. Another result of arrested weathering is the occurrence of hard ore in the minor rolls, between the small ravines which carry wet-weather streams. The extremely hard ore sandstone at the Evans drift, and the hard ore beneath it show that the requisite weathering-action has not occurred at this point.

The presence of ground-water below the hard ore and above the soft ore indicates the important part that such water plays in the leaching of these beds.

That the present ore-bed is a replaced limestone is shown by the fossiliferous limestone-bed at the mill-dam, which can be traced until it becomes the hard or soft ore-bed. The limestone among the hard ore at the Parker drift also indicates that the present ore-bearing bed was once a limestone, as do also the corals found in the hard ore which are not entirely replaced by iron-ore.

The dark-blue fossiliferous limestone probably owes its color to the presence of ferrous iron carbonate, for small particles can be observed in the hand-specimen which have the cleavage of siderite and are either crystals of ferrous carbonate or calcite crystals carrying more or less iron oxide. Probably the iron carbonate is in isomorphous combination with the calcite. The fossiliferous limestone contains but about 2.12 per cent. of ferrous oxide, FeO , and 2.35 per cent. of ferric oxide, Fe_2O_3 , so that there must have been some addition of iron. There is very much more calcium carbonate in the hard ore than in the soft ore, indicating that it has not been removed by waters

bearing iron, while the soft ore contains more silica than the hard ore, probably denoting that the waters which dissolved and carried away the calcium carbonate from the limestone left iron and silica behind.

The fossils observed in the fossiliferous limestone and in the hard ore are identical, except that those in the latter have been largely replaced, with the single exception of the corals, which were never found to have been replaced. The soft ore contains the same crinoid fragments as are found in the fossiliferous limestone and in the hard ore, and these fragments are sometimes wholly replaced by silica. An examination of the fragments of crinoids, bryozoans, and brachiopods found in all the ore-occurrences reveals the fact that they can be traced in all stages of their replacement by iron oxide, from the fossiliferous limestone, where they are generally entirely calcareous, through the hard ore, where they are partly replaced, to the soft ore, where they are less numerous, but still plainly recognizable and nearly entirely replaced by iron oxide. The crinoid fragments are the most numerous of all the organic fragments, and are generally the only remains found in the soft ore.

The concretions, either of round or of oval shape, are siliceous, and may be isolated by treatment of the fossiliferous hard or soft ore with hydrochloric acid. They have a concentric character, and the silica is nearly always iron-stained. They give an axial cross with crossed nicols. As compared with the crinoid fragments they are a minor constituent of the ores and are very much smaller. They are extremely fragile, and can be mounted only with great difficulty.

An examination of the sections cut from the fossiliferous limestone and the hard and soft ores demonstrates that the original cementing material between the organic fragments and the concretions is calcite. This mineral constitutes what may be called the "ground-mass" of the rock- or ore-sections. Replacement appears to commence first on this calcite cement, and by means of the cleavage-cracks has access to the organic fragments. Nothing was noticed which would lead to the inference that the fragments had been replaced before they were cemented together, except that there was an apparent slight replacement of the interior of the fragments in some of the limestone-sections where there was no external coating of iron

oxide. The analogous replacement of Medina sandstone indicates that these Clinton shales in Stone Valley contain sufficient iron to produce beds of iron-ore when it is concentrated within the space of a few inches, as it is in the Clinton bed in this valley. An examination of sections cut from the Medina sandstone and from the ore shows a filling of iron oxide between the quartz-grains of the sandstone. An analogous change occurs in the limestone, except that the quartz-grains are here represented by calcareous organic fragments, while the filling between is calcite. These shales are competent iron-forming beds.

The conclusion that the iron-content of the Clinton iron-ore beds of Stone Valley is due mostly to replacement by removal and enrichment seems unavoidable when it is considered that but a portion of the fossiliferous limestone or of the hard ore is found to contain iron oxide when examined in thin sections under the microscope. The calcite cement makes up by far the greater portion of the section. An analysis of the limestone shows that it contains but 2.12 per cent. of FeO and 2.35 per cent. of Fe_2O_3 . This seems much too small an iron-content to yield as rich an ore as the soft ore, simply by removal of the calcium carbonate. Field-conditions, such as the occurrence of weathered shales, buff-colored clays, and iron-stained sandstones, prove that the action of replacement is still progressing.

3. *Origin of the Clinton Iron-Ore of Stone Valley.*

As a result of my studies, I have reached the conclusion that but a very small part of the iron-content found in the present ore-bed was deposited in it when the bed was laid down. This small amount of iron is represented by the iron-content of the siliceous concretions. By far the greater portion of the present iron-content of these Stone Valley ore-beds is believed to have been laid down in the beds of shale overlying the ore-beds as an original constituent of such shale-beds, and subsequently transferred from these shale-beds to the bed of fossiliferous limestone which formerly occupied the location of the present ore-bed. I agree with Professor Smyth as to the original deposition of the iron-content of these beds only so far as the siliceous concretions are concerned, but I differ with him in ascribing

ing the present richness of the beds very largely to the addition of iron and not alone to the removal of the limestone, as Professor Smyth asserts. The grounds for these conclusions, briefly summarized, are:

A. The character of the iron in the ore-concretions where it is associated with silica;

B. The invariable association of the soft, rich ore with the leached, decolorized shales and of the hard, lean ores with unweathered bright-red shales;

C. The relations of the ores to the shattered sandstones and to the topographic situation of the ores;

D. The fact that analogous replacements are now taking place in the Medina;

E. The observed progressive steps in the transformation of the limestone to an ore, which may be followed in the field, in thin sections under the microscope, and in chemical analyses; and, finally,

F. The absence of conditions, such as local crumpling, including a shrinking of the strata, pointing to a relative rather than an absolute enrichment of the ores.

A. *The Iron of the Concretions.*—Upon treating the fossiliferous limestones and the hard and soft ores with hydrochloric acid, small concretions are isolated. These concretions are composed of silica and iron oxide combined, and appear to be made up of concentric coatings of these substances. This is the case with the concretions in the limestone as well as those in the hard and soft ores. On the other hand, the organic fragments, composed of remains of crinoids, bryozoans, and brachiopods, are entirely calcareous in the limestone, and are gradually replaced by iron oxide until they are almost entirely composed of iron oxide in the soft ore. That the iron and silica probably entered the limestone together is shown by the fact that the crinoid fragments are often not affected by the hydrochloric acid, and can be isolated in the same manner as the siliceous concretions, since their iron-content is bound up with the silica.

B. *Association with Shales.*—Every occurrence of the richer iron-ores shows them to be in association with altered shales, whose weathered character is indicated by the great predominance of the yellow and gray colors which they possess. These shales are brick-red in the upper portion, or that part overlying

the iron-ore beds, and inclined to be massive in places; under the ore-bed they are brown to gray in color, and in the lowermost portions contain numerous olive-colored bands, in which the color is due to the presence of ferrous silicates.

It is evident from a study of the conditions in Stone Valley that weathering influences and rock-disintegration have been very important factors in the formation of the Clinton ore of this region. At all the mines where soft ore is found the shales immediately above the ore-bed are found to be of a light-buff color, to have an unctuous feel and to show the effects of percolating waters. These shales have been deprived of their iron-content by these waters, which have then carried it to the underlying limestone and there deposited it as an ore. That this must be the case can be shown by a consideration of the columnar section of the Clinton group in Brush Ridge. At the top of the columnar section is a mass of brick-red shale which locally becomes quite massive. This red shale is succeeded by beds of dark-gray shale which lie just above the ore sandstone. In both these masses of shale there are found, here and there, olive-colored bands, varying from 1 to 20 ft. thick, which owe their color to the presence of ferrous iron silicates. That portion of the column lying below the ore-bed and above the Medina contact contains numerous beds of olive-colored shales, but no limestones are found in these beds near them. In other portions of central Pennsylvania the Block iron-ores, which are really ferruginous sandstones, occur at this horizon. The Upper Clinton shales, dark-red in color, where unweathered, and containing the olive-colored beds, have probably furnished the source for the Clinton ore of this region.

C. *Relations to Overlying Sandstone and to Topography.*—Everywhere in Stone Valley where Clinton ore is found the shales over the ore have been eroded and the ore sandstone appears at the surface, broken and weathered. On the other hand, on Standing Stone mountain, where the topographic conditions were such that the Upper Clinton shales were but slightly eroded, no soft ore is found. The ore must have come from the Upper Clinton shales. In this connection it is interesting to refer to a paper by James P. Kimball,¹⁰ in which he speaks of the oc-

¹⁰ Genesis of Iron-Ores by Isomorphous and Pseudomorphous Replacement of Limestone, etc., *American Geologist*, vol. viii., No. 6, p. 356 (Dec., 1891).

currence of Clinton iron-ore on the flanks of Tussey, Dunnings, and Wills mountains in southern Pennsylvania, in these words :

" All of these ores owe their development, as I believe, exclusively to secular replacement of elevated parts of these limestones [thin crinoidal limestones]—not, as sometimes explained, to direct sedimentation in whole or in part. For wherever oolitic iron-ores are developed within the Clinton series, they are found to graduate into non-ferriferous limestones, more or less crinoidal, and usually in circumstances only moderately favorable to weathering action. An equally significant fact is the absence of valuable iron-ores where the Clinton limestone, as in southern Ohio, is massive and unaccompanied by a considerable thickness of overlying shales. Wherever, on the other hand, the limestone occurs in numerous thin beds, and so alternates with more or less ferruginous shales ; or again, wherever overtopped by shales, it seldom fails, especially in steep dips, to graduate unequally into oolitic hematite by replacement."

The opinion that beds of iron-ore are derived from shales and slates does not seem unwarranted when some of the facts surrounding the occurrence of different iron-ores are considered. All through the geological column from Cambrian ores to those of Carboniferous age, iron-ores are found near shales and slates, the latter generally pyritous. It is only necessary that there be soluble limestones present to receive the ore and topographic conditions favorable to a slow movement of percolating waters to insure ore-deposition. Organic matter is usually abundant in the shales. The Appalachian ore-occurrences are in areas where great structural movements have occurred, and the beds carrying the ore have been left in a position favorable to a slow and efficient action of drainage-waters. The fact that the maximum thickness of Clinton iron-ores, about 22 ft., occurs in the southern Appalachians, where little more than 200 ft. of the entire Clinton group remains, seems significant.

There seems to be an intimate relationship between the amount of shattering which the ore sandstone covering the ore has received and the weathering of the limestone. The fossiliferous limestone exposed at the mill-dam, which is here of a blue-gray color, and evidently contains ferrous carbonate, lies practically horizontal under a rather thickly-bedded mass of dark-colored, unweathered shale about 30 ft. thick. This bed of fossiliferous limestone is one mass of fragments of brachiopods, bryozoans, and crinoids, and can be identified by these organic remains. Following the ridge westward, the shale over the fossiliferous limestone disappears and exposes the ore sandstone,

which lies immediately below the shale and over the ore. The ore sandstone is found to be broken soon after leaving the mill-dam, and the soil in the roadway changes from a dark-gray color to a light buff. Boulders of the ore sandstone are here much shattered and weathered and show, on freshly-broken surfaces, traces of hematite. All through Stone Valley, at every occurrence of soft ore it is found to be overlain by broken ore sandstone. Another argument in favor of the importance of weathering effects in the formation of these Clinton iron-ore beds in Stone Valley is the fact that the beds are generally rich and soft when lying at a dip of from 10° to 20° , and under a surface where the slope of the covering strata is about the same.

D. Analogous Replacements.—That these Clinton shales contain disseminated in them sufficient iron to furnish the 12- to 18-in. bed of oölitic iron-ore now found in Stone Valley can be demonstrated by a reference to a very lean and highly siliceous iron-ore found at various points in Stone Valley, viz., at Steffy's hotel, at Joseph Bowman's house, near Old Monroe Furnace, at the place where the county-road crosses Big Laurel Run, on Greenlee mountain, and at E. Musser's house. At all these places the White Medina sandstone projects through the Clinton lower shales, nearly always forming an arch, with the crown partly eroded. In all such occurrences the shale is found to be weathered to a soft clay, of a buff color; and boulders of the White Medina sandstone, as well as the beds in place, are found to be transformed to a lean iron-ore which yields on analysis from 17 to 30 per cent. of iron and is very high in silica. The sandstone can be found in all stages of transition, from the pure white sandstone through that bearing a yellowish-brown outer shell of iron oxide about $\frac{1}{8}$ in. thick with a clear white interior, to the fine-grained ore, which is an entirely transformed sandstone. The soil yielded by the shale appears to act most rapidly and efficiently on the sandstone boulders, but also affects the sandstone when in place. Microscopic sections of the sandstone in all processes of transformation, show it to be of a rather fine grain and exhibit the iron oxide filling all the spaces between the separate grains of the sandstone. That this sandstone ore was not an original deposition can be shown at Steffy's hotel, where it occurs as an ore immediately in front of the hotel; but 300 ft. to the north,

where the sandstone is not covered by disintegrating shale, it is of a pure white color and contains no iron oxide. On the sides of the road-cutting near the hotel small pieces of sandstone, containing about 20 per cent. of iron oxide, can be observed projecting from the bed of loose, dark-gray shale in which they lie. It is thus seen that analogous replacements are taking place to-day, except that the cementing substances in sandstones and not fossiliferous limestones are being substituted.

E. *Observed Progression in Alteration of Limestone to Ore.*—That the ore-bed was once a limestone is shown by the occurrence at the mill-dam and by the finding of limestone-masses in the Parker drift and Bookhammer drift. The limestone in both of the last-named places is of a bluish-gray color and contains coral remains in an excellent state of preservation. Moreover, the “working ground,” *i. e.*, the lean sandstone overlying the ore, is at Bookhammer’s drift almost rich enough in iron to be classed as an ore, thus indicating that there has been a replacement of this sandstone at this point. That the mine-water is not found above the hard ore, but below it, and is found above the soft ore, would seem to indicate the importance of such waters in the present instance. In central Pennsylvania the prospectors for brown hematite (or limonite) expect to find it only in places where there is limestone, hence it would seem reasonable to expect a replacement of the limestone in this instance. The unchanged masses of limestone are usually found on the crests of minor rolls on the sides of the ridge, indicating that their presence is due to inefficient drainage-action. Another important fact bearing upon the question of the action of meteoric waters is that the hard ore is usually massive and difficult to mine, and is not broken up by numerous joints and vugs as is the soft ore. The joints and cavities, existing generally only in the soft ore, contain clay and water when in place and when freshly opened up. Hard ore becomes extremely hard when exposed to the sun and atmospheric influences, while soft ore disintegrates under like conditions. Soft ore when freshly mined contains a considerable amount of water between its individual grains, while hard ore does not, and never disintegrates upon exposure to the atmosphere.

Megascopically, the individual grains of the hard ore are

roughly oval in shape and rather flat. In thin sections of both hard and soft ore, as well as in those of the bluish-gray fossiliferous limestone, numerous remains of brachiopods, bryozoans, and crinoids were found. The latter fragments are most persistent and are clearly visible in the soft ore. A large portion of the crinoid fragments appear to be replaced by iron and silica, as the iron-stain was found in the interior of the crinoid fragments even under a high power. Under the microscope, the crinoid fragments appear concentric, and a replacement of their calcite by silica and iron oxide might give rise to a simulated concentric or oölitic structure. The replaced fragments have a concentric appearance, but are truly of organic character. Iron oxide has replaced the substance of these organic fragments from the exterior, approaching them by means of the cleavage-cracks in the calcite cement lying between the different organic fragments. Some organic fragments in the limestone and lean ore are wholly calcareous. There seems to be a change in the cement first, and, succeeding this, a replacement of the organic fragments. In thin sections of soft ore the cement is wholly replaced, while the crinoid fragments, some rounded and others oval-shaped, are seen rather dimly but still distinctly. When these fragments of crinoids have been replaced by silica they become isolated in treating the soft ore with hydrochloric acid, in the same way as the concretions are separated.

An examination of the results of the chemical analyses of the hard and soft ore and the fossiliferous limestone seems to yield results which bear out the theory of replacement and enrichment. Little or no calcium carbonate is found in the soft ore, while there is more than 22 per cent. of calcium oxide and more than 18 per cent. of carbon dioxide in the hard ore, in which the pure, unchanged limestone-masses are found, which seems to point to the lack of action of percolating waters. It should be noticed that there is a considerable difference in the amount of insoluble silica found in the two varieties of ore, the soft ore having 16.40 while the hard ore has but 3.58 per cent.; the iron and silica probably, in large measure, entered the limestone together.

F. *Relative vs. Absolute Enrichment.*—There seems to be a lack of conditions indicating a relative rather than an absolute en-

richment. The overlying shales show the action of percolating water and a probable removal of their iron-content. An examination of the ore-sections and of the results of chemical analysis of the ores and limestone seems to develop the fact that the original iron-content of the limestone is too small to furnish such a rich ore as the Stone Valley occurrence merely by the results of relative enrichment.

III. ORIGINAL SOURCE OF THE IRON.

The main point at issue between Professor Smyth and me is the original source of the iron. Professor Smyth holds that all of the iron was originally deposited in the limestone, the CaCO_3 being later removed and the iron-content of the bed thereby relatively increased. I hold that the iron was only in part original, and that the calcium carbonate was not simply removed but really replaced by iron derived from the overlying shales through the agency of percolating waters.

If Professor Smyth's hypothesis is correct, there should be :

1. A sufficient amount of iron in the original limestone to make an ore.

2. A distinct shrinkage of the ore-bed as compared with the thickness of the unaltered limestone or an unusually porous ore.

3. This shrinkage should be accompanied by evidences of more or less local movement consequent upon the attempt of the adjacent rocks to adapt themselves to the shrinkage, and this should be observed both in microscopic sections of the ores and rocks and in the field-occurrences.

4. The specific gravities of the ores and rocks should also indicate the changes produced by the leaching-out of the calcium carbonate.

A comparison of the results of the analyses of the fossiliferous limestone and the hard and soft ores yielded important results, which appear to refute completely the hypothesis of original deposition. According to the values obtained, 1 cu. ft. of the fossiliferous limestone contains about one-fourteenth as much iron as the hard or soft ores; and if there has been no addition of iron from extraneous sources, there must have been a removal of 13 cu. ft. of limestone for every cu. ft. of ore now found in the bed. Such excessive shrinkage is not demanded by the field-conditions, but, on the contrary, field-observations

and detailed microscopic studies show that no such shrinkage could have taken place.

The ore-beds traced along their strike from the richest concentrations to the unaltered fossiliferous limestones show no appreciable change in thickness, and the contiguous beds show no local adjustments or crinklins, such as must have occurred if the ore is only the ferruginous remnant of the original limestone. Microscopic examinations point to the same end, in that the rocks and ores examined show no minute adjustments or rearrangements resulting from a loss of the calcareous portions, but on the contrary the progressive steps in the gradual replacement of the calcium carbonate by iron from some outside source may be easily traced in the different sections.

If leaching was the only factor brought into play, and the enrichment was only a relative one and not absolute, then the following conclusions may be drawn: In the fossiliferous limestone the CaCO_3 and SiO_2 equal 90 per cent. of the whole rock, while in the hard ore the sum of the CaCO_3 and SiO_2 equals 43 per cent. of the whole, therefore the 10 per cent. of the limestone which is other than CaCO_3 and SiO_2 is concentrated to 57 per cent. in the hard ore, or as 1 : 5.7. This being true, the sum of both irons of the limestone is increased in the ratio of 1 to 5.7, which equals $4.47 \times 5.7 = 25.48$ per cent. But the iron of the hard ore is 49.50 per cent., or double what concentration alone would produce, therefore there must have been an addition of iron from exterior sources in order to account for the iron-content of the soft ore.

Looking at the matter from the standpoint of the relative specific gravities of the fossiliferous limestone and the hard and soft ores, we have the following conclusions: Taking into consideration the fact that field-conditions show no evidences of shrinkage of the ore-beds (and that they are hard and compact and not at all porous), then if leaching alone acted and no matter was added from outside, and the stratum of limestone did not shrink (and field-conditions show no evidences of shrinkage), then the hard and soft ores should be quite porous and much lighter than the limestone, as they, composed of the non-leachable matter, must occupy the space originally occupied by the limestone. This is contrary to the actual conditions, as both the hard and soft ores are compact and heavier than the lime-

stone; hence, there must have been an addition of iron from the outside. There is 90 per cent. of extractive or soluble matter, *i. e.*, CaCO_3 and SiO_2 , and 10 per cent. of non-extractive or insoluble matter. This 10 per cent. of non-extractive material becomes 57 per cent., or is increased in the ratio of 1 : 5.7. This being true, and no material being added from extraneous sources, the specific gravity of the hard ore should be the following, using the determined specific gravity of the limestone, 2.69:

1 : 5.7 :: x : 2.69; whence $x = 0.47$, which is, of course, absurd.

1. *Conclusions.*

The observations made in the field while studying the Stone Valley ores, as well as the study of the microscopic sections of the ores and limestones, lead me to the conclusion that by far the greater part of the iron of these ores is due to the replacement of limestone and concentration of the ore. The very small amount of iron represented by the iron oxide intimately combined with the silica in the concretions isolated by treating both varieties of ore with hydrochloric acid, may be due to original deposition. It is also probable that all of the iron present as the carbonate in isomorphous mixture with the calcium carbonate was deposited originally, although some of this may have arisen in the early replacement of the lime of the carbonate by the iron. But the quantity of originally-deposited iron so found is extremely small in comparison with the total iron-content of the ore. The iron oxide found in the calcite cement and forming coatings around the organic fragments represents by far the greater amount of iron in the ore.

In the Clinton upper red shales the iron exists as a peroxide, and in this form is insoluble and cannot be affected by ordinary surface-waters, but rain-water containing carbon dioxide falls upon this shale after coming into contact with the organic matter in the leaves and soil; chemical reactions result, the peroxide (ferric oxide) is reduced to ferrous oxide, and carbonic acid formed by decomposition of organic matter unites with the ferrous oxide to form iron carbonate or siderite. This is carried in solution until it comes in contact with the fossiliferous limestone, when the lime is replaced by iron and the calcium carbonate is carried away in solution. The iron is prob-

ably present first in the limestone in isomorphous combination, as the appearances seem to indicate this.

Professor Smyth failed to find any siderite in his rocks, and concluded that the iron-ore must have been an original deposit and not formed as the result of enrichment through the intermediate formation of a carbonate. I have, however, found what is, apparently, siderite in my rocks, and the presence of the iron in combination with carbon dioxide is corroborated by the chemical analyses. If one makes a distribution of the different elements of the analysis of limestone among the minerals found, assuming that part of the lime is united with the phosphorus to form a lime phosphate, it readily appears that the soluble ferrous iron is present in the form of siderite unless part of the CO_2 is unsatisfied. The same is true in part for the hard ore, but does not hold in the case of the soft ore, where all of the iron is oxidized to the ferric state.

The iron carbonate was formed under conditions in which organic matter was in excess, later percolating waters acted, after structural movements had occurred, and the water, now containing small quantities of organic matter, caused a deposition of ferric oxide and left the ore as it is found to-day, soft and pure.

BIOGRAPHICAL SKETCH.

John Joseph Rutledge was born in North Alton, Illinois, March 10, 1870. His early education was received in the public school and High School of Alton, Illinois, and in Shurtleff College, Upper Alton, Illinois. In the fall of 1889 he entered the University of Illinois at Champaign, and in 1894 received the degree of Bachelor of Science in mining engineering in the School of Mining Engineering, College of Engineering. His vacations were spent in practical work in the coal-mines of Illinois, the greater portion of the time being occupied in making mine surveys and platting the same. Immediately after graduation he was employed as Construction Foreman by the St. Louis, Chicago and St. Paul Railroad. During 1895 he was employed as Assistant Mine Manager for the Consolidated Coal Company of St. Louis, Missouri, and served as Mine Examiner during a portion of the time. In January, 1895, he passed the examination before the State Mine Examining Board and received a life certificate of competency as mine manager. During a portion of 1896 he was temporarily in charge of mines at Spaulding, Illinois, and later did special work as a traveling correspondent and statistician for the *Engineering and Mining Journal* and *Mineral Industry*. From January, 1897, until July, 1899, he was Mine Manager for the Litchfield Mining and Power Company, Litchfield, Illinois, and was later Superintendent of the Wabash Coal Company, Dawson, Illinois. He acted as Superintendent for the Eldon Coal and Mining Company, Centerville, Iowa, during 1900, and was awarded a certificate of competency by the Iowa State Board of Mine Examiners. He resigned this place to enter the Johns Hopkins University.

Since coming to the University he has pursued work in chemistry under Professor Renouf and in geology under Professor Clark, Professor Reid, Professor Mathews, Professor Shattuck, and Dr. Fassig. His especial field of work has been in economic geology, and during the past three field-seasons he has been working on the iron-deposits of central Pennsylvania. During part of the time spent at the University he has acted as Consulting Engineer for companies owning iron-, coal-, and pyrite-mines.

